Physical Properties of Shelled and Kernel Walnuts as Affected by the Moisture Content

Ebubekir ALTUNTAS and Mehmet ERKOL

Department of Agricultural Machinery, Faculty of Agriculture, University of Gaziosmanpasa, Tasliciftlik, Tokat, Turkey

Abstract

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The variations in physical properties such as the size dimensions, unit mass, sphericity, projected area, bulk density, true density, volume, coefficient of friction on various surfaces, and terminal velocity of shelled and kernel walnuts as a function of the moisture content were determined. With an increase in the moisture content, the sphericity, projected area, bulk density, volume, and porosity of shelled and kernel walnuts increased, whereas the true density linearly decreased. Studies on rewetted walnuts showed that the terminal velocity increased from 14.17 m/s to 15.50 m/s, and from 12.60 m/s to 14.35 m/s, for shelled and kernel walnuts, respectively. The static and dynamic coefficients of friction of shelled and kernel walnuts on chipboard and plywood surfaces also increased linearly with an increase in the moisture content.

Keywords: walnut (*Juglans regia* L.); physical properties; moisture content

The walnut (*Juglans regia* L.) has a rich nutritient composition (oil, protein, vitamin and mineral) and high calorific content. Walnuts are mainly produced in China, USA, Iran, and Turkey. Turkey provides 11% of the world production of 1 150 000 t (FAO 2006).

Walnut cultivars differ in the ability to produce light-coloured kernels under different climatic conditions. Important quality factors of walnuts are the size, colour, level of internal damage caused by insects, and level of external damage, such as adhering hull tissue and broken shells (Ramos 1998). Walnuts are the second most important product after hazelnuts of Turkey. Walnuts have a special value in traditional Turkish foods. The most important walnut cultivars are: Şebin, Yalova 1, 2, 3, 4 and Bilecik (Şen 1986; Akça 2001; Çağlarırmak 2003). The physical properties of shelled and kernel walnutsas established by the Turkish Standard Institute – TS 1275 and TS 1276 (TSE 1990, 1991) are the shelled and kernel weights, kernel ratio, shell shape, and size dimensions (TSE 1990, 1991).

The information on the physical properties such as the size dimensions, sphericity, porosity, volume, bulk and true densities, coefficient of friction, and terminal velocity is important to design the equipments used in harvesting, transporting, storing, handling, and processing of shelled and kernel walnuts. The coefficient of friction of shelled and kernel walnuts on various surfaces is also important to design the conveying, transporting, and storing equipments. Bulk density and porosity play an important role in designing the storage facilities of walnuts.

In recent years, the variation of physical properties as affected by the moisture content have been studied in various nut crops such as castor nuts (Olaoye 2000), raw cashew nuts (Balasubramanian 2001), hazelnuts (Aydin 2002), Turkish mahalebs (Aydin *et al*. 2002), arecanut kernels (Kaleemullah & Gunasekar 2002), groundnut kernels (Olajide & Igbeka 2003), almond nuts and kernels (Aydin 2003), shea nuts (Aviara *et al*. 2005), pine nuts (Özgüven & Vursavuş 2005), African nutmegs (Burubai *et al*. 2007), and olive fruits (Kılıçkan & Güner 2008). Koyuncu *et al*. (2004) and Sharifan and Derafshi (2008) studied the mechanical behaviour of walnut cultivars under compression loading. However, there is a paucity of technical information and data in the scientific literature with regards to the physical properties of shelled and kernel walnuts as affected by the moisture content. Therefore, the objective of this study was to investigate physical properties of shelled and kernel walnuts as affected by the moisture content changes.

MATERIALS AND METHODS

The walnuts were obtained in the production year of 2006 from the walnut orchard of a native producer in Denizli, Turkey. The Yalova-1 walnut cultivar was used in this study. The samples were cleaned to remove the impurities and damaged and broken walnuts. The initial moisture contents of the walnut samples were determined by oven drying at 105 ± 1°C for 24 h (Suthar & Das 1996). The desired moisture contents of the shelled and kernel walnuts were obtained using the method recommended by Olaniyan and Oje (2002). In this method, the walnut samples at the desired moisture levels were prepared by soaking the walnuts in water for 3 h and 12 h, respectively. The samples were stored in cellophane bags in the freezer at about –10°C for 48 hours. Subsequently, they were removed from the freezer 24 h before the experiment to allow their gradual thawing and obtain moisture equilibrium within the samples. The moisture contents for the shelled and kernel walnuts ranged between 11.46% to 23.16% and 4.93% to 32.25% d.b. (dry basis), respectively.

Physical properties of shelled and kernel walnuts were investigated at three moisture levels. Ten replications of each test were conducted at each moisture level. For each moisture content, the length, width, thickness, and unit mass of the shelled and kernel walnuts were measured with randomly selected 100 walnuts. The length, width, thickness, and shell thickness of the walnuts were measured by a dial-micrometer to an accuracy of 0.01 mm. The geometric mean diameter (D_g) and sphericity (Φ) of the shelled and kernel walnuts were calculated using the following relationships (Mohsenin 1970):

$$D_g = (LWT)^{1/3} \quad (1)$$

$$\Phi = \left[\frac{D_g}{L}\right] \times 100 \quad (2)$$

where:
L – length
W – width
T – thickness in mm (Figure 1)

The unit mass of the shelled and kernel walnuts was measured with a digital electronic balance with a sensitivity of 0.01 g. The shelled and kernel walnuts were placed on a sheet of paper, and the boundary lines were traced. The projected area was measured by a digital planimeter (Roller-Type, KP90N, No.R02443, Koizumi, Japan) (Sirisomboon *et al*. 2007).

The true density of the shelled and kernel walnuts was determined by the toluene (C_7H_8) displacement method (Mohsenin 1970; Sitkei 1976; Sacilik *et al*. 2003). Bulk density was determined using the standard test weight procedure (Singh & Goswami 1996).

The porosity (ε) was determined by the following equation:

$$\varepsilon = \left[1 - \frac{\rho_b}{\rho_t}\right] \times 100 \quad (3)$$

where:
ρ_b, ρ_t – bulk and true densities, respectively (Mohsenin 1970)

The coefficient of friction of the shelled and kernel walnuts was measured by a friction device. The device of friction force measuring was formed by a metal box, a friction surface, and an electronic

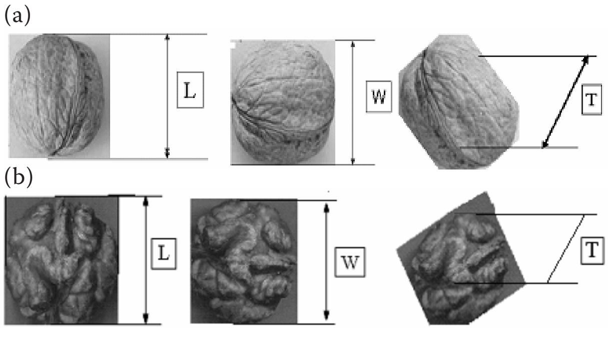

Figure 1. Description of three perpendicular dimensions of shelled (a) and kernel (b) walnuts

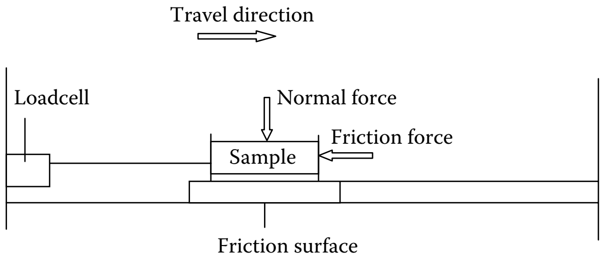

Figure 2. A schematic appearance of the measuring device of friction force

unit (Kara *et al.* 1997; Altuntas & Demirtola 2007). Friction force was measured with a loadcell, converted by the ADC (Analog digital converter) card, and the data were recorded in a computer. The schematic appearance of the friction force measuring device is shown in Figure 2. The coefficient of friction (μ) is defined as the ratio between the measured friction force (F) and normal force (N). The maximum value of the friction force was obtained when the box started operating. This value was used to calculate the static coefficient of friction. While the box continued to slide on the friction surface at 0.02 m/s velocity, the dynamic coefficient of friction (average value) was measured. The experiments were conducted using friction surfaces of chipboard and plywood. For each experiment, the sample box was emptied and refilled with a different sample of the same moisture content (Sacilik *et al.* 2003).

The terminal velocities of the shelled and kernel walnuts were measured using an air column. A walnut sample was dropped into the air stream at the top of the air column through which air was blown upwards to suspend the walnuts in the air stream in each test. The air velocity was measured by Testo 425 (Lenzkirch, Germany measurement range 0–20 m/s) electronic anemometer having a least 0.01 m/s count (Mohsenin 1970).

Statistical analyses were conducted with Microsoft Excel and SPSS 10.0 software (SPSS 2000). The results of the experiments were analysed based on the randomised complete block design with a split plot.

RESULTS AND DISCUSSION

Size dimension

Approximately 72% of the shelled walnuts had a length ranging from 42.79 mm to 45.46 mm, about 78% of the samples a width ranging from 35.96 mm to 37.58 mm, about 75% a thickness ranging from 34.21 mm to 36.21 mm, and about 79% a unit mass ranging from 17.42 g to 19.79 g at 11.46% moisture content (Figure 3). With kernel walnuts, about 85% had a length ranging from 32.08 mm to 35.42 mm, about 79% a width ranging from 28.08 mm to 32.33 mm, about 96% a thickness ranging from 23.50 mm to 27.25 mm, and about 69% a unit mass ranging from 6.96 g to 8.58 g at 4.93% moisture content (Figure 4). The average length, width, thickness, geometric mean diameter, and unit mass of the shelled walnut ranged between 44.25 mm to 44.80 mm, 36.58–37.00 mm, 34.99 mm

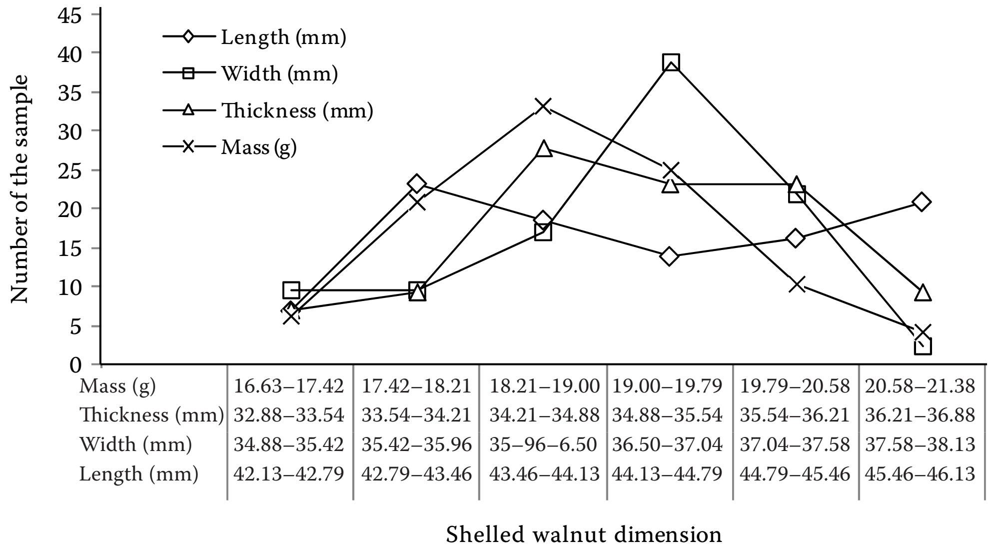

Figure 3. The frequency distribution curves of shelled walnut length, width, thickness and unit mass of the walnut at 11.46% moisture content (d.b.)

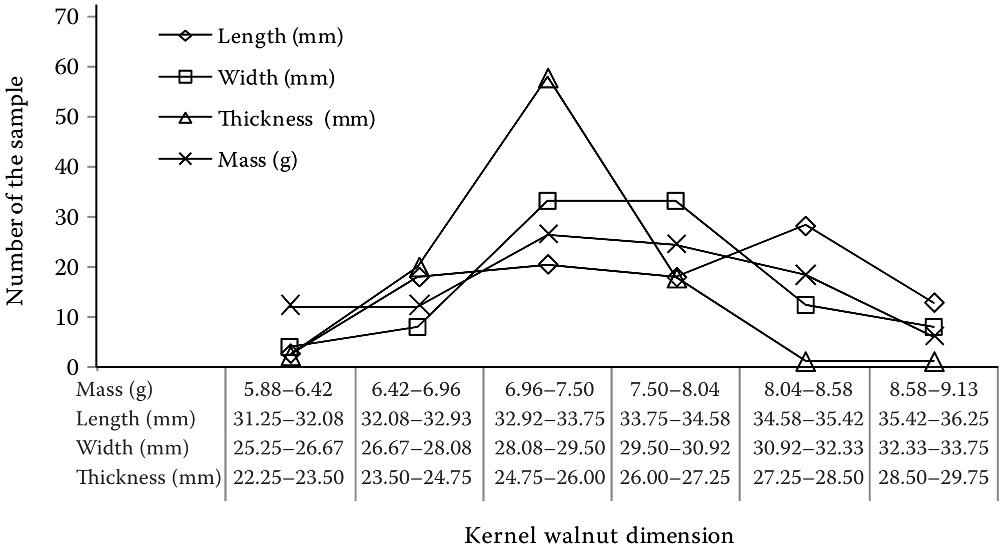

Figure 4. The frequency distribution curves of kernel walnut length, width, thickness and unit mass of the walnut at 4.93% moisture content (d.b.)

to 35.55 mm, 38.18 mm to 38.97 mm and 18.84 g to 21.28 g, respectively, as the moisture content increased from 11.46% to 23.16% d.b.

As the moisture content increased from 11.46% to 23.16%, the average shell thickness of the walnuts increased from 1.628 mm to 1.667 mm. The effect of the moisture content on the shell thickness of walnuts was not significant.

Sphericity

The results obtained of sphericity of the shelled and kernel walnuts are presented in Figure 5. As the moisture content increased from 11.46% to 23.16%, the average sphericity of the shelled walnuts increased from 86.34% to 86.85%, respectively. The corresponding sphericity values for the kernels increased from 85.26% to 86.03% as the moisture content increased from 4.93% to 32.25%, respectively. The effect of the moisture content on kernel sphericity of walnuts was statistically significant ($P < 0.05$). The relationship between the moisture content (M_c) and sphericity of the shelled walnuts (Φ_s) and sphericity of the kernel walnuts (Φ_k) were defined by the following equations;

$$\Phi_s = 86.01 + 0.26\,M_c \quad (R^2 = 0.779) \tag{4}$$

$$\Phi_k = 84.93 + 0.39\,M_c \quad (R^2 = 0.936) \tag{5}$$

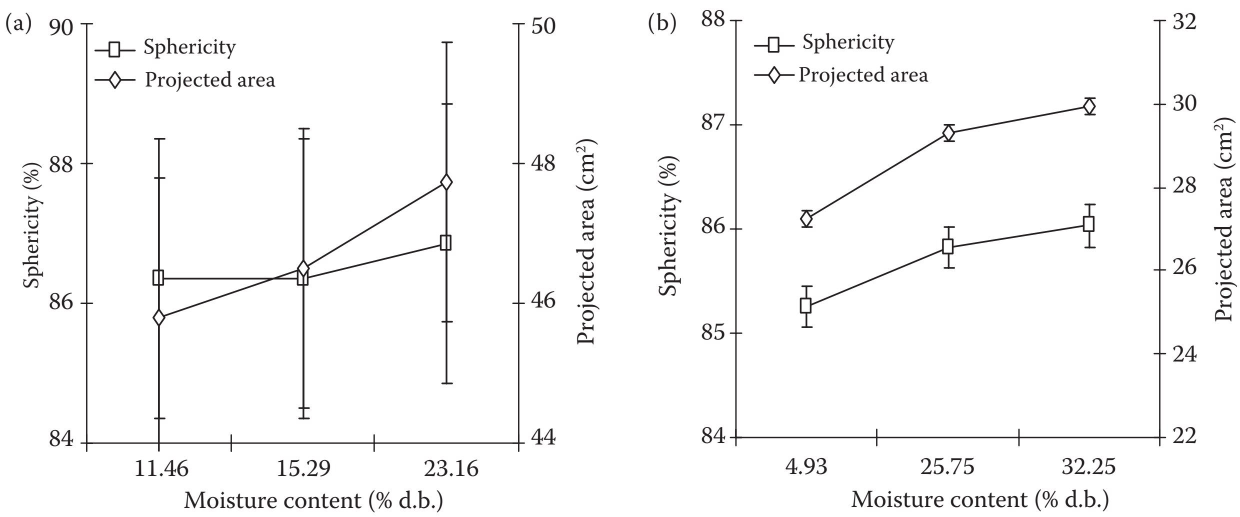

Figure 5. Effect of moisture content on sphericity and projected area of shelled (a) and kernel (b) walnuts

Similar trends have also been reported by Aydin *et al.* (2002) for Turkish mahaleb and by Gezer *et al.* (2003) for apricot pit and kernel.

Projected area

The experimental results for the projected area of the shelled and kernel walnuts with respect to the moisture content are given in Figure 5. Linear increases in the projected areas for the shelled and kernel walnuts were observed from 45.80 cm^2 to 47.74 cm^2, and from 27.24 cm^2 to 29.93 cm^2 with the increasing moisture content from 11.46% to 23.16%, and from 4.93% to 32.25%, respectively. The value of the walnut projected area generally increased with an increase in the moisture content with both the shelled and kernel walnuts. A sligth increase (4.06%) with the shelled and a considerable increase (8.99%) with kernel walnuts occured in the projected areas at the moisture contents studied (Figure 3). The effects of the moisture content on the projected areas of the shelled and kernel walnuts were statistically significant ($P < 0.05$). The relationships between the moisture content (M_c) and the projected area of the shelled walnuts (P_s) or the projected area of the kernel walnuts (P_k) were described by the following equations:

$$P_s = 44.74 + 0.97\ M_c \quad (R^2 = 0.975) \qquad (6)$$

$$P_k = 26.14 + 1.35\ M_c \quad (R^2 = 0.910) \qquad (7)$$

Similar trends have also been reported by Gezer *et al.* (2003) for apricot pit and kernel, by Aydin (2002) for hazelnut and kernel, by Aydin (2003) for almond nut and kernel, by Pliestic *et al.* (2006) for filbert nut and kernel, and by Aydin (2006) for peanut and kernel..

Bulk density

The bulk density at different moisture levels for the shelled (ρ_{bs}) and kernel walnuts (ρ_{bk}) varied from 259.19 kg/m^3 to 318.04 kg/m^3 and from 227.22 kg/m^3 to 248.63 kg/m^3, respectively (Figure 6), indicating an increase in the bulk density with an increase in the moisture content. The bulk density of the walnuts increased for the shelled ones and the kernels as the moisture content increased. The effect of the moisture content on the bulk density of the shelled walnuts and of the kernel walnuts was statistically significant ($P < 0.05$). The relationships between the moisture content (M_c) and bulk densities of shelled and kernel walnuts were described by the following linear equations:

$$\rho_{bs} = 232.57 + 29.43\ M_c \quad (R^2 = 0.974) \qquad (8)$$

$$\rho_{bk} = 218.60 + 10.71\ M_c \quad (R^2 = 0.898) \qquad (9)$$

Positive linear relationships between the bulk density and the moisture content have also been reported by Paksoy and Aydin (2004) for edible squash seed, by Çalışır and Aydin (2004) for cherry laurel, and by Kabas *et al.* (2006) for cactus pear.

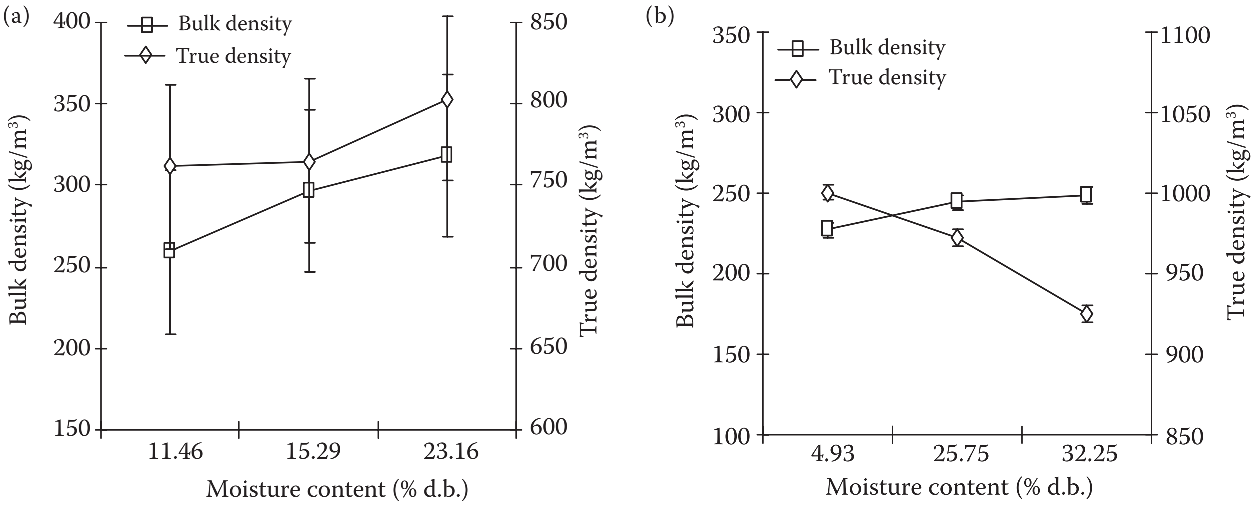

Figure 6. Effect of moisture content on bulk density and true densities of shelled (a) and kernel (b) walnuts

True density

The true density of the shelled and kernel walnuts at different moisture levels varied from 761.60 kg/m^3 to 803.42 kg/m^3 and from 1000.44 to 924.91 kg/m^3, respecively (Figure 6). The true density of the shelled and kernel walnuts generally decreased as the moisture content increased. The effect of the moisture content on the true density of the shelled walnuts was not statistically significant. An increase (5.20%) for the shelled walnuts and a decrease (7.55%) for the kernel walnuts in true density were recorded in the moisture content range from 11.46% to 23.16% and from 4.93% to 32.25% for the shelled and kernel walnuts, respectively. Negative linear relationships between the moisture content (M_c) and the true density of the shelled (ρ_{ts}) and kernel walnuts (ρ_{tk}) were described by the following equations:

$$\rho_{ts} = 734.86 - 20.91\,M_c \quad (R^2 = 0.811) \tag{10}$$

$$\rho_{tk} = 1041.40 - 37.77\,M_c \quad (R^2 = 0.979) \tag{11}$$

The negative linear relationships between true density and the moisture content have also been reported by Pliestic *et al.* (2006) for filbert nut and kernel, by Aydin (2002) for hazelnut and kernel, and by Akar and Aydin (2005) for gumbo fruit, respectively.

Porosity

The results obtained for the porosity of the shelled and kernel walnuts are presented in Figure 7. The porosity of the shelled and kernel walnuts decreased with an increase in the moisture content. The effect of the moisture content on porosity was statistically significant. The relationships between the moisture content (M_c) and porosity of the shelled (ε_s) and kernel (ε_k) walnuts were described by the following equations:

$$\varepsilon_s = 68.08 - 2.78\,M_c \quad (R^2 = 0.852) \tag{12}$$

$$\varepsilon_k = 79.27 - 2.09\,M_c \quad (R^2 = 0.992) \tag{13}$$

Similar results were also reported by Gezer *et al.* (2003) for apricot pit and kernel, by Aydin *et al.* (2002) for Turkish mahaleb, and by Çalışır and Aydin (2004) for cherry laurel.

Volume of walnut

The data obtained for the volumes of the shelled and kernel walnuts are presented in Figure 7. The average volumes of the shelled and kernel walnuts increased with an increase in the moisture content. The volume increases (6.08%) for the shelled and (13.17%) for the kernel walnuts were recorded at the moisture contents studied. The effect of the moisture content on the shelled and kernel walnuts volumes was significant ($P < 0.05$). The relationships between the moisture content (M_c) and the volumes of the shelled (V_s) and kernel (V_k) walnuts were described by following equations:

$$V_s = 28.44 + 0.96\,M_c \quad (R^2 = 0.975) \tag{14}$$

$$V_k = 12.68 + 1.03\,M_c \quad (R^2 = 0.914) \tag{15}$$

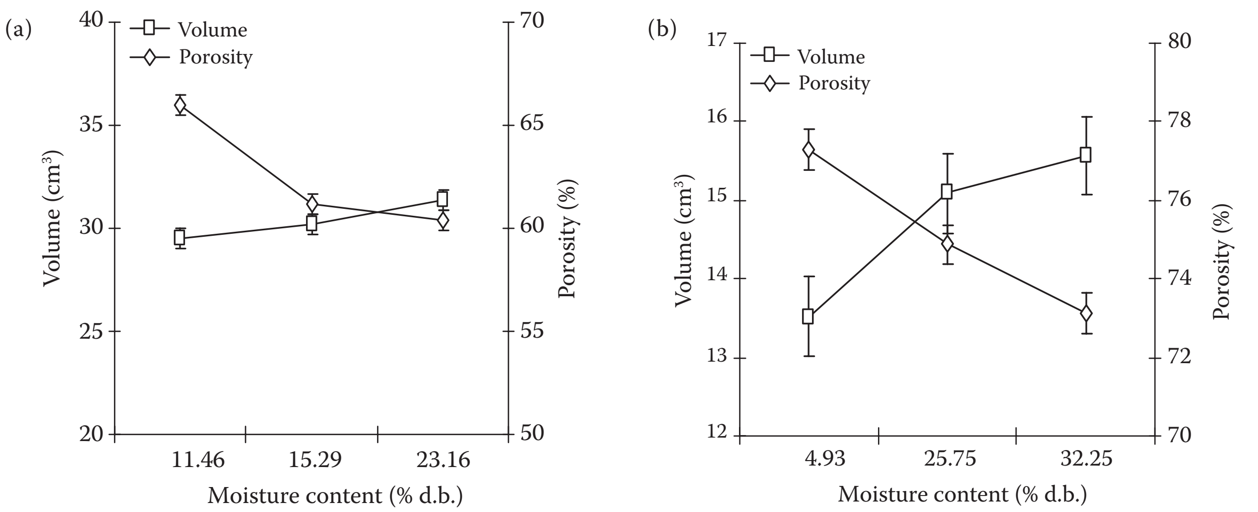

Figure 7. Effect of moisture content on volume and porosity of shelled (a) and kernel (b) walnuts

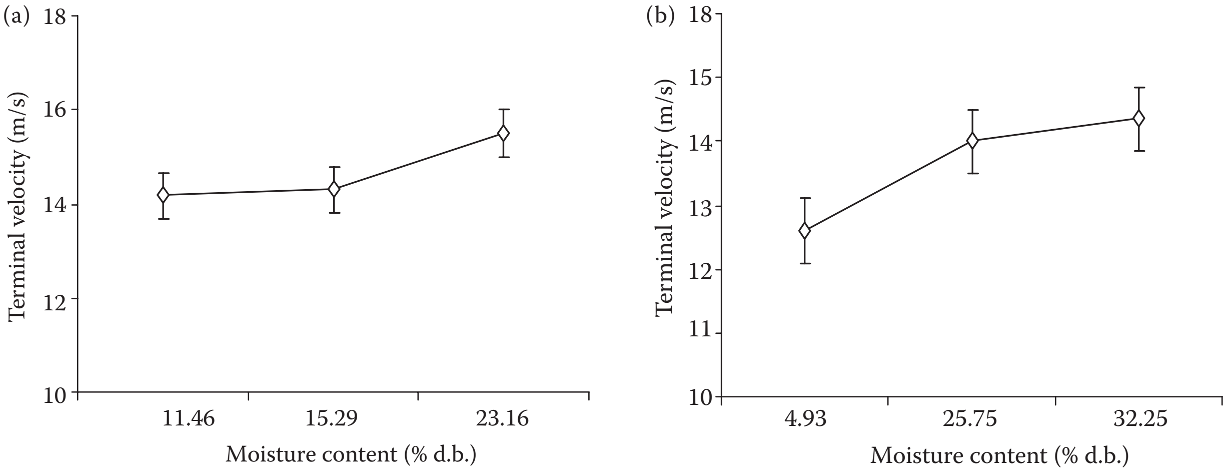

Figure 8. Effect of moisture content on terminal velocity of shelled (a) and kernel (b) walnuts

Similar incremental trends have been reported by Özarslan (2002) for cotton seed; by Sahoo and Srivastava (2002) for okra seed, and by Sessiz *et al*. (2007) for caper.

Terminal velocity

As the moisture content increased, the average volumes of the shelled and kernel walnuts increased (Figure 8). The terminal velocity of the shelled walnuts increased from 14.17 m/s to 15.50 m/s with the increase in the moisture content studied, respectively. The terminal velocity of the kernel walnut increased from 12.60 m/s to 14.35 m/s. The effect of the moisture content on the terminal velocity of the kernel walnut was statistically significant ($P < 0.01$). The relationships between the moisture content (M_c) and the terminal velocity of the shelled walnuts (V_{ts}) and that of the kernel walnuts (V_{tk}) were described by the following equations:

$$V_{ts} = 13.33 + 0.67\ M_c \quad (R^2 = 0.823) \tag{16}$$

$$V_{tk} = 11.90 + 0.88\ M_c \quad (R^2 = 0.893) \tag{17}$$

The results are similar to those reported by Aydin *et al*. (2002) for Turkish mahaleb, by Aydin

Table 1. Regression coefficients and coefficient of determinations for static and dynamic coefficients of friction on various friction surfaces

Walnut	Surface	Regression coefficient		Coefficient of determination (R^2)
		intercept (A)	slope (B)	
Shelled	**static coefficient of friction**			
	chipboard	0.42	0.04	0.923
	plywood	0.25	0.05	0.996
	dynamic coefficient of friction			
	chipboard	0.40	0.03	0.964
	plywood	0.26	0.02	0.964
Kernel	**static coefficient of friction**			
	chipboard	0.12	0.01	0.750
	plywood	0.09	0.02	1.000
	dynamic coefficient of friction			
	chipboard	0.11	0.01	0.750
	plywood	0.08	0.02	0.964

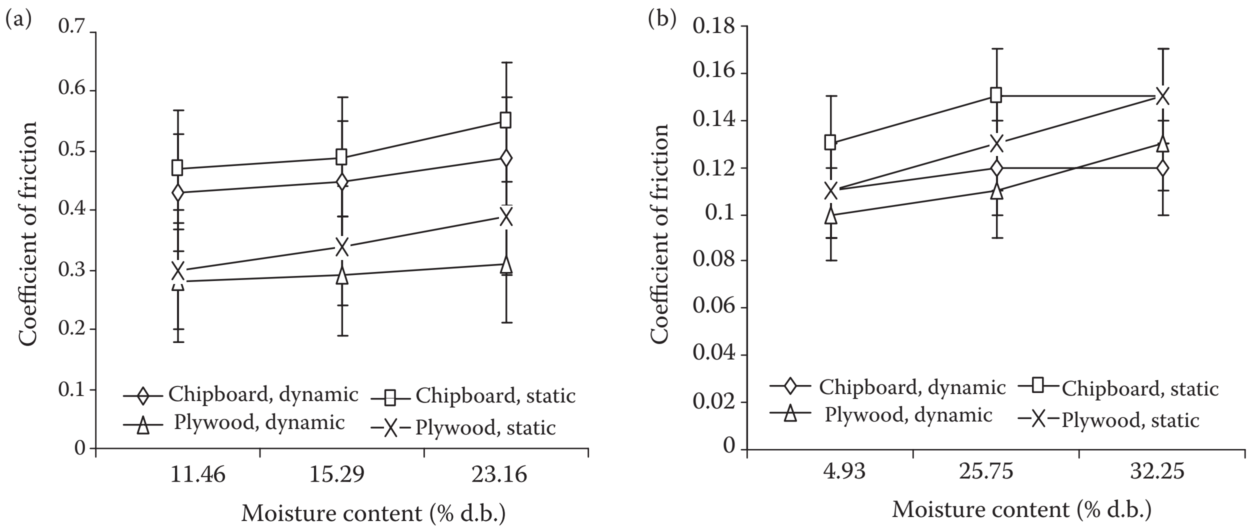

Figure 9. Effect of moisture content on static and dynamic coefficient friction of shelled (a) and kernel (b) walnuts against chipboard and plywood surfaces

(2002) for hazelnut, by Aydin (2003) for almond nut and kernel, by Paksoy and Aydin (2004) for edible squash seed, and by Akinci *et al*. (2004) for *Juniperus drupacea* fruits. The terminal velocities of the walnuts obtained in this study were higher than of the above mentioned agricultural materials. This probably resulted from the mass increase of the individual walnuts per unit frontal area which were exposed to the air flow with an increase in the moisture content (Konak *et al*. 2002).

Static and dynamic coefficient of friction

The results of the static and dynamic coefficients of friction on various surfaces, namely chipboard and plywood surfaces, obtained with the shelled and kernel walnuts, were compared and are given in Figure 9. The static coefficient of friction was higher at any moisture content than the dynamic coefficient of friction. The static and dynamic coefficients of friction linearly increased with respect to the moisture contents on the two surfaces. The linear equations for both static and dynamic coefficients of friction on all three surfaces could be described as:

$$\mu = A + BM_c \qquad (18)$$

where:

μ – coefficient of friction

A, B – regression coefficients; the corresponding values are given in Table 1.

The static and dynamic coefficients of frictions for the shelled walnuts were higher on chipboard than those obtained on plywood for all the moisture contents studied. Due to the increasing adhesion between the product and the surface of the shelled and kernel walnuts at higher moisture content (Nimkar & Chattopadhyay 2001; Konak *et al*. 2002; Özarslan 2002); the moisture content of the walnuts increased and the static and dynamic coefficients significantly increased. The effects of the moisture content and friction surfaces on the static and dynamic coefficients of friction were significant for the kernel walnuts ($P < 0.05$). The effects of the moisture content and plywood friction surface on the static and dynamic coefficients of friction were significant for the shelled walnuts ($P < 0.05$). Similar results were found by others (Pliestic *et al*. 2006; Aydin 2006).

CONCLUSIONS

The following conclusions are drawn from the investigation on the physical properties of shelled and kernel walnuts as functions of the moisture content.

The size dimensions, unit mass, sphericity, projected area, bulk density, volume, porosity, and terminal velocity of the shelled and kernel walnuts increased.

The true density linearly decreased with an increase in the moisture content.

The static and dynamic friction coefficients of the shelled and kernel walnuts on chipboard and plywood surfaces increased with an increase in the moisture content.

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Corresponding author:

Assoc. Prof. Dr. Ebubekir Altuntas, University of Gaziosmanpasa, Faculty of Agriculture, Department of Agricultural Machinery, 60240 Tasliciftlik, Tokat, Turkey
tel.: + 90 356 252 16 16, e-mail: ealtuntas @ gop.edu.tr